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Influence of Air Gaps on Long Rod Penetrators Attacking Multi-Plate Target Arrays

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Influence of Air Gaps on Long Rod Penetrators Attacking Multi-Plate Target Arrays

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Abstract

Quarter-scale shots of an L/D 20 65-g U-3/4 Ti long rod penetrator were fired into a series of rolled homogeneous armor targets at normal incidence at nominally 1600 m/s. The purpose was to determine the effect of small air gaps in a laminated stack of plates. Three replications of shots were fired at a monolithic target, a laminated target with plate faces in intimate contact, and at laminated targets separated by 1.55- and 3-mm air gaps. A single shot was fired at a laminated stack separated by 6-mm air gaps. The laminated targets presented significantly less ballistic resistance than did the monolithic targets, and ballistic resistances for the targets with an air gap were less than that for the laminated targets with no air gaps. Computational simulations using the code CTH did not correspond exactly with the experiments, but did show the same observed trends.

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1. Introduction

As part of the screening process used by many researchers in kinetic energy (KE) penetrator development, improvement, and acceptance testing, penetration capabilities into rolled homogeneous armor (RHA) is routinely used as a benchmark. The thickness of RHA plates is nominally limited to a maximum of 150 mm. To achieve the thickness needed for testing modern anti-armor long rod penetrators, it is necessary to assemble stacks of individual plates. At the U.S. Army Research Laboratory (ARL), such RHA block targets that are routinely used for penetration evaluation are fabricated with single plates (generally 150 mm thick) that are placed in intimate facial contact and then welded together to form large block targets. Additionally, mild steel straps and angle iron are used to further weld and band the RHA plates together. This fabrication method produces a block target that will not easily separate into individual plates when impacted with a KE penetrator at typical ordnance velocity (1600 m/s).

However, this procedure is not universally used. At other facilities, different configurations are sometimes employed in fabricating RHA block targets that are used for evaluating penetration capabilities. In one case, individual plates are firmly clamped together into a test fixture with the objective of also minimizing any gaps or spaces between plates. Compared to the welding and banding method, individual plate contact in this fixture does not always occur, leaving small gaps between adjacent plates.

In an effort to gain some insights into the possible influence of plate spacing on the ballistic performance of RHA block targets, the Lethal Mechanisms Branch at ARL designed and conducted a small scale experimental series aimed at evaluating the penetration capabilities of a small scale penetrator against a monolithic RHA target and other laminated targets constructed with various air spaces between individual target plates. Additionally, numerical simulations using an Eulerian computational technique were performed to observe the predicted influence of spacing on penetrator performance.

2. Experimental Procedure

A 13-shot, nominally quarter-scale experimental series was conducted in Experimental Facility 110G of the Lethal Mechanisms Branch. A hemispherical-nose, 65 gram, Uranium – 3/4 Titanium rod was packaged with a Polypropylux 944A* sabot, then push launched from a 37-mm experimental laboratory gun. The length of each rod was 120 mm, while the diameter was 6 mm

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* Polypropylux 944A is a trademark of Westlake Plastics, Lenni, PA.

(length to diameter ratio [L/D] 20) (Figure 1). Our objective was to launch each rod at the typical ordnance velocity of ~1600 m/s. Five slightly different targets were used for this test series. The first was a 152.4-mm-thick monolithic RHA block. The second was made with six plates each with a thickness of 25.4 mm that were tightly banded together with duct tape to eliminate any spacing between plates. The third was similarly configured with six plates each with a thickness of 25.4 mm that were also banded together with a 1.55-mm-thick mild steel spacer placed between the outer edges of each RHA plate to introduce a controlled air gap between the central facial area of each plate (projectile flight path). The fourth and fifth types were also similarly configured but with 3- and 6-mm-thick mild steel sheets used respectively to introduce different air spaces between each RHA plate within each target (Figures 2–4). All the RHA blocks and 25.4-mm plates used for those targets were cut from the same sheet of armor and therefore had the same hardness, measured as Brinell hardness number 255.
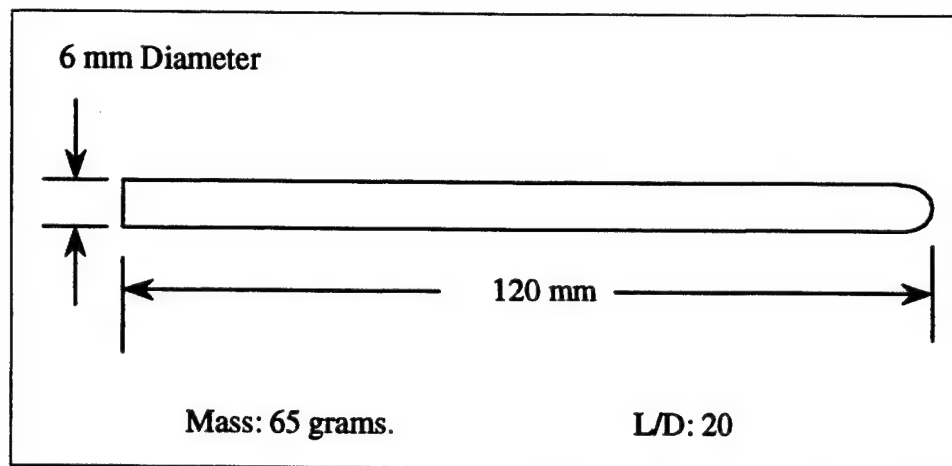

Figure 1. U-3/4 Ti experimental penetrator.

3. Experimental Results and Discussion

Table 1 presents the pertinent data for the 13 targets used. Our initial test matrix included three each of four different target configurations. However, after a preliminary evaluation of the differences in penetration between the various targets, we thought it would be useful to shoot an additional shot with an even larger air gap between the 25.4-mm plates. Figure 5 presents the same data plotted as penetration/length (P/L) vs. air gap.

Examining the data, the monolithic (solid RHA) target clearly has significantly more ballistic resistance than does the equivalent laminated target. A trend of increased RHA penetration with increased plate separation is evident from our limited experiments. The data suggest a P/L value of 1.1 for the RHA block target and 1.2 for the laminated target with the greatest separation.
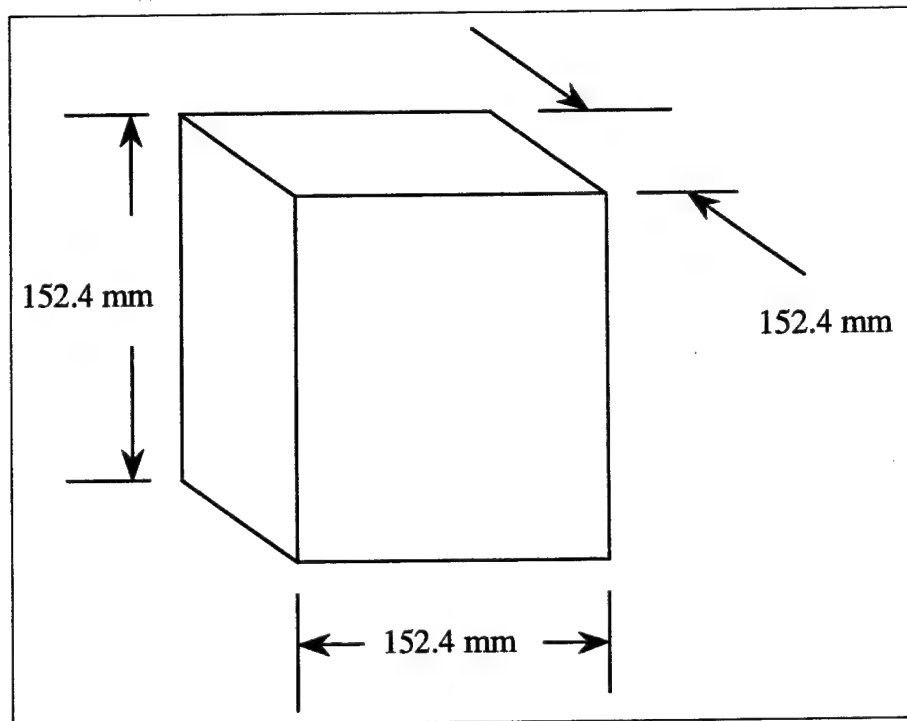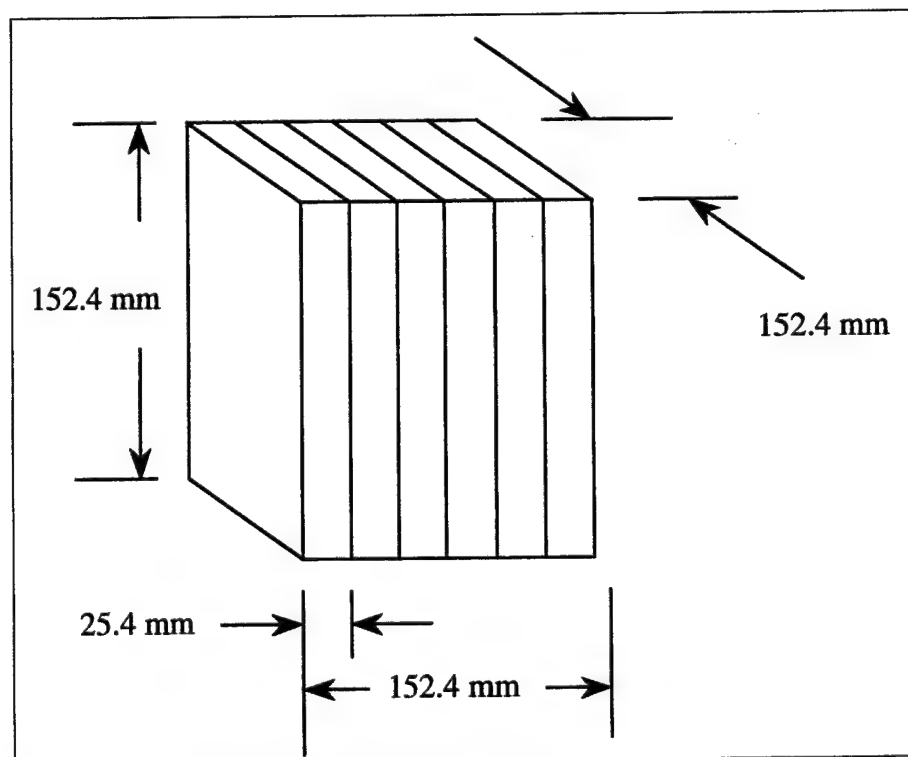
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Figure 2. Monolithic RHA block.

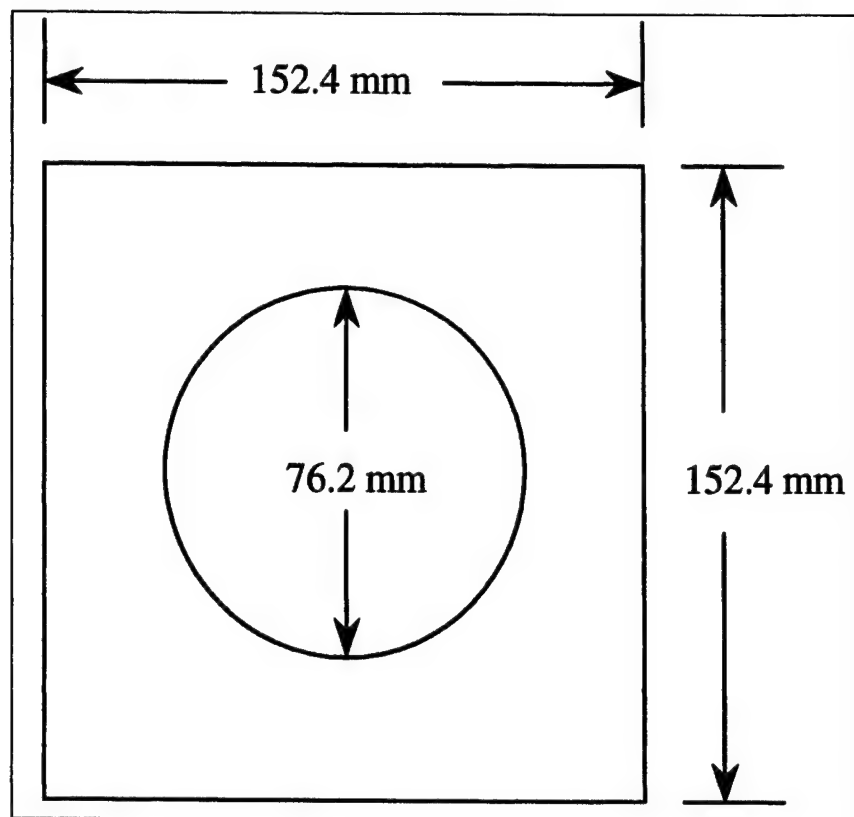Figure 3. 25.4-mm RHA plates in intimate contact.

Figure 4. Design of mild steel sheets used to separate plates for the third, fourth, and fifth target types.

Table 1. Results with individual shot data.

| Shot No.	Target	Mass (g)	Pitch (deg)	Yaw (deg)	Striking Velocity (m/s)	Penetration (mm)	P/L
1	152.4-mm RHA block	65.08	0	0.75	1656	130.0	1.08
2	152.4-mm RHA block	65.08	0	0	1599	129.0	1.08
3	152.4-mm RHA block	65.12	0	1.75	1614	124.0	1.03
4	6 each 25.4-mm RHA plates	64.99	0.25	0	1607	140.0	1.17
5	6 each 25.4-mm RHA plates	64.86	0	0	1609	138.0	1.15
6	6 each 25.4-mm RHA plates	64.16	0	0	1611	139.0	1.16
7	6 each 25.4-mm RHA plates with 1.55-mm air gap between plates	64.80	-0.25	0	1595	143.0	1.19
8	6 each 25.4-mm RHA plates with 1.55-mm air gap between plates	64.97	0	0	1607	148.0	1.23
9	6 each 25.4-mm RHA plates with 1.55-mm air gap between plates	64.97	-0.5	0	1606	144.0	1.20
10	6 each 25.4-mm RHA plates with 3-mm air gap between plates	64.74	-0.25	0	1606	143.0	1.19
11	6 each 25.4-mm plates with 3-mm air gap between plates	65.08	-0.25	-0.25	1605	144.0	1.20
12	6 each 25.4-mm RHA plates with 3-mm air gap between plates	65.03	-0.25	-0.5	1593	142.0	1.18
13	6 each 25.4-mm RHA plates with 6-mm air gap between plates	65.20	0	-0.25	1567	144.0	1.20
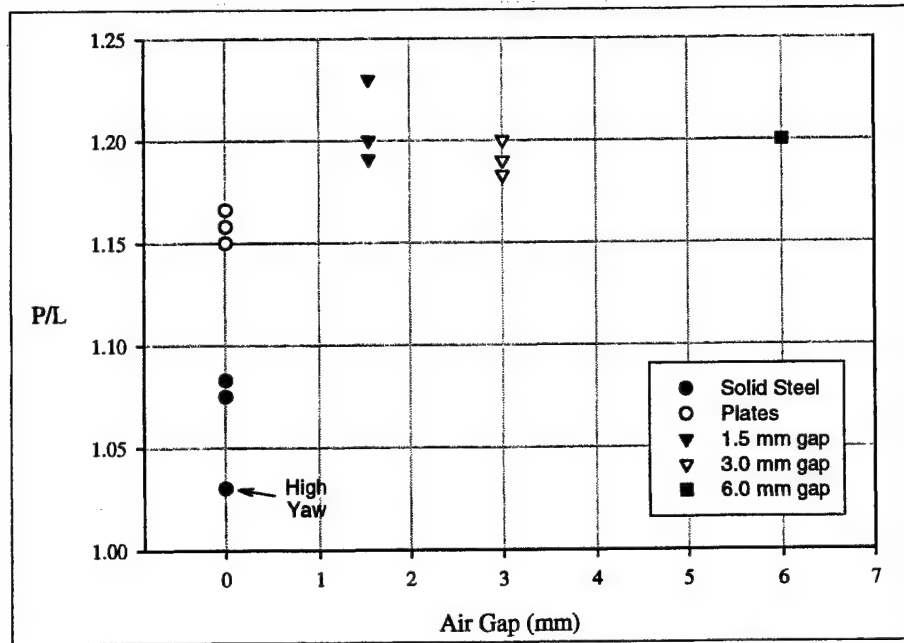
Figure 5. P/L vs. air gap for experimental data.

Hypothetically, assuming a difference between P/L values of 1.1 and 1.2 for a 700-mm-long penetrator, the potential difference in penetration capability for RHA would be ~70 mm. However, we lack enough data points to definitively conclude this. Because the implications for measuring long rod anti-tank munition performance could be highly significant, further experiments involving other target configurations should be conducted. This effort should provide better insights into the effects of plate spacing when evaluating the penetration performance of long rod penetrators against RHA.

4. Computer Simulations

For additional insights, we performed computer simulations to predict the depth of penetration into the various target configurations. The same geometries for the penetrator and target configurations used in our experiments were modeled. We also used a single impact velocity of 1600 m/s. The March 1999 version of the CTH code[1] was used for our calculations. The Johnson-Cook strength and fracture models were used for both the penetrator and target materials, coupled with the Mie-Gruneisen equation of state. An axisymmetric geometry was used for all of the simulations.

Table 2 presents the penetration predictions obtained from the computer calculations. For cases 3, 4, and 5, the target simulants included the air gaps as part of the target thickness. As such, the

[1] McGlaun, J. M., S. L. Thompson, and M. G. Elrick. "CTH: A Three-Dimensional Shock Wave Physics Code." *International Journal of Impact Engineering*, vol. 10, pp. 351–360, 1990.

Table 2. Penetration predictions obtained from computational results.

Case	Target Simulant	Computed Penetration Depth (mm)	Adjusted Depth Into RHA (mm)	P/L
	Sample Calculations			
1	152.4-mm RHA block	115.9	—	0.97
2	6 each 25.4-mm RHA plates	116	116	0.97
3	6 each 25.4-mm RHA plates with 1.5-mm air gap between plates	137.9	130.4	1.09
4	6 each 25.4-mm RHA plates with 3.0-mm air gap between plates	148	133	1.11
5	6 each 25.4-mm RHA plates with 6.0-mm air gap between plates	164	134	1.12

reported penetration depth for each simulant is the depth of penetration into the target relative to the front face, including gaps. An adjustment of this depth was made by subtracting the air gaps to obtain the actual predicted value of steel penetrated and for comparison to the experimental data. Those values are also reflected in Table 2. Figure 6 presents the same data plotted as P/L vs. air gap together with the plotted P/L experimental data. Once again, a careful study of Table 2 and Figures 7–11 reveals a trend towards increased RHA penetration as we change from the monolithic block and increase the separation of the spaced targets. As in the case of our experimental data, we see a P/L difference of ~0.1 between the predicted valve of the monolithic block and the target with the largest air gap.
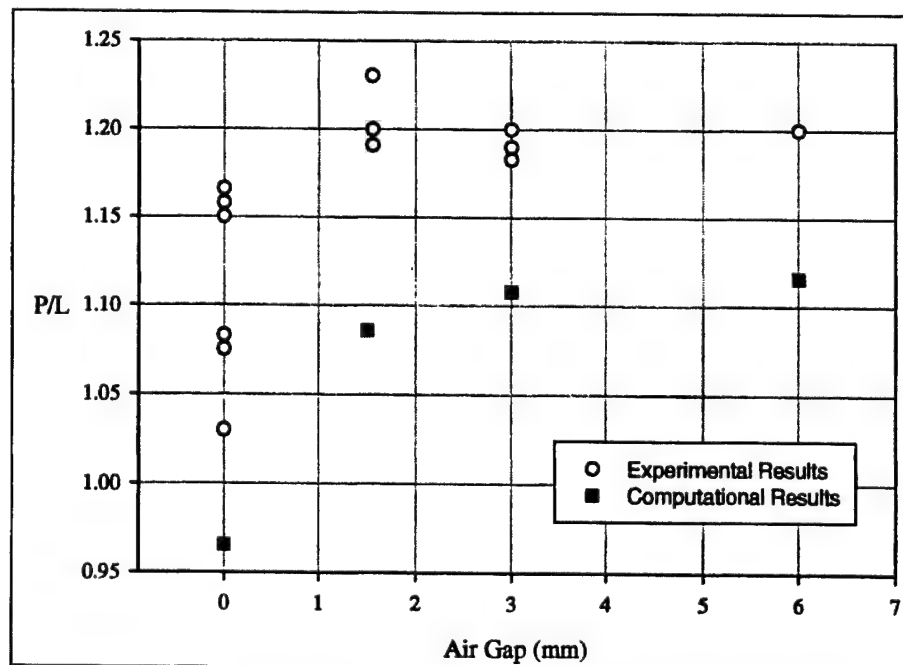

Figure 6. P/L values vs. air gap for the experimental and computational results.
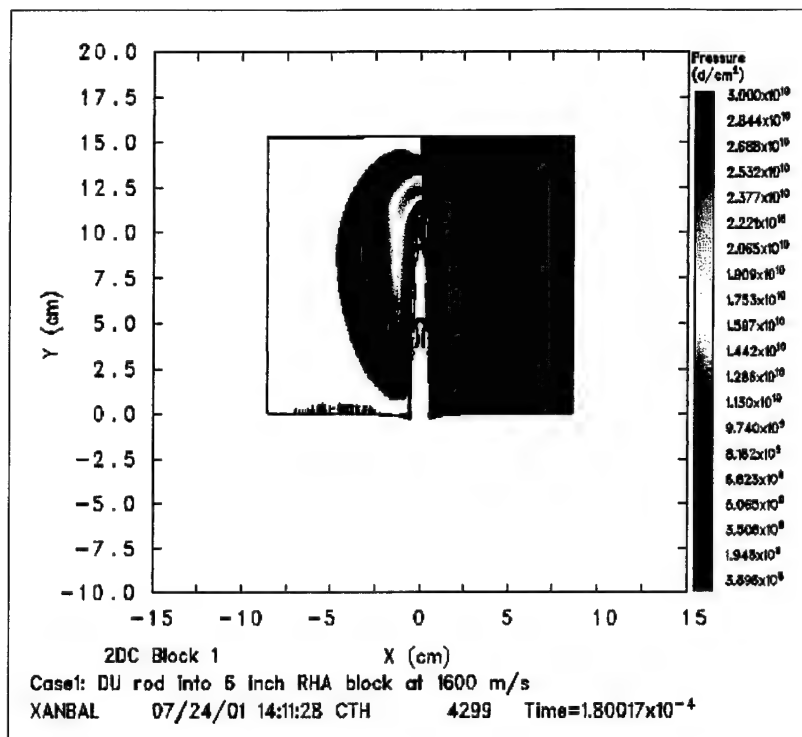
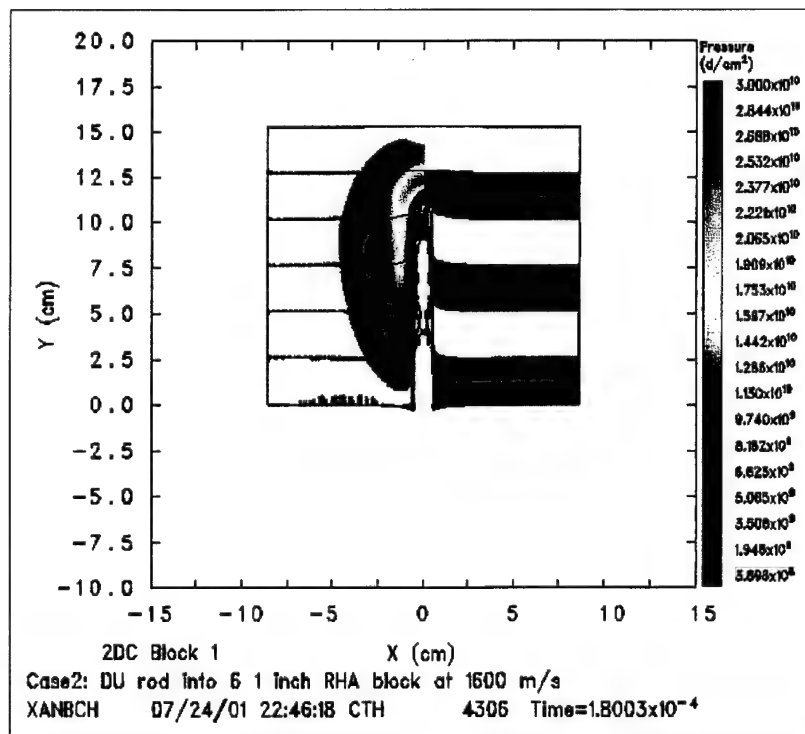Figure 7. Computer simulation of penetration into monolithic RHA block.

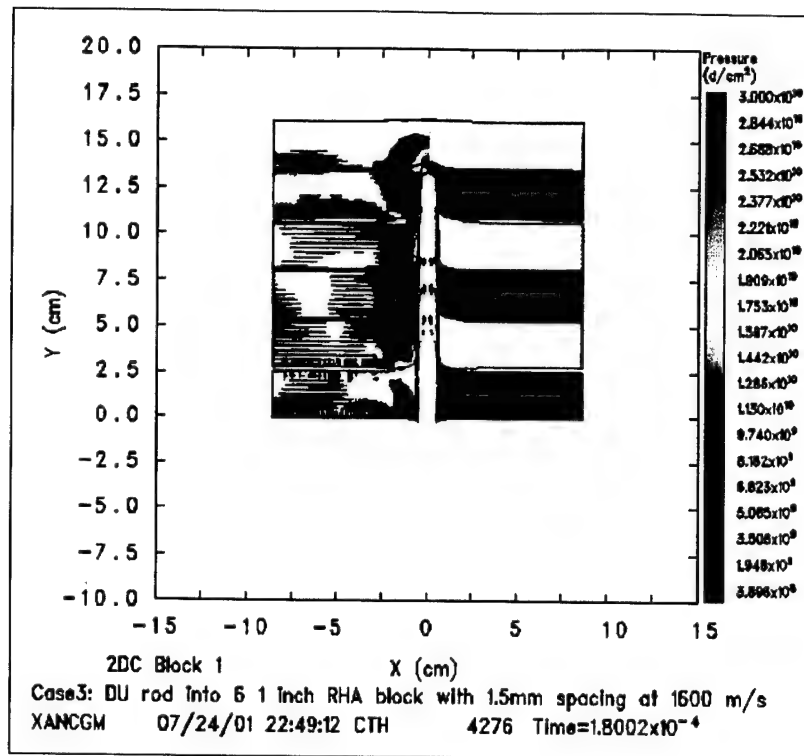Figure 8. Computer simulation of penetration into stacked plates in intimate contact.

Figure 9. Computer simulation of penetration into stacked plates separated by 1.55-mm air gaps.
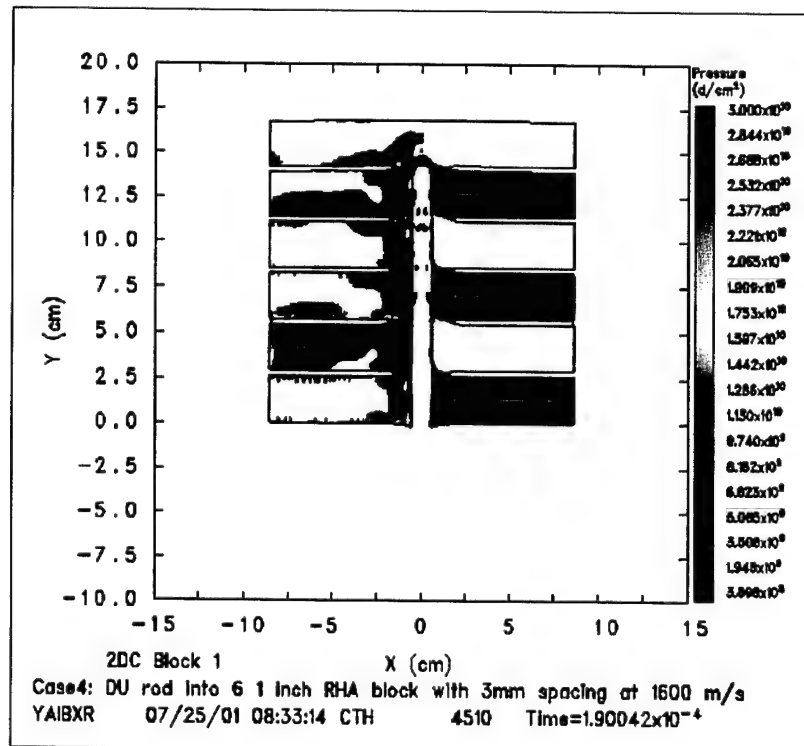

Figure 10. Computer simulation of penetration into stacked plates separated by 3-mm air gaps.
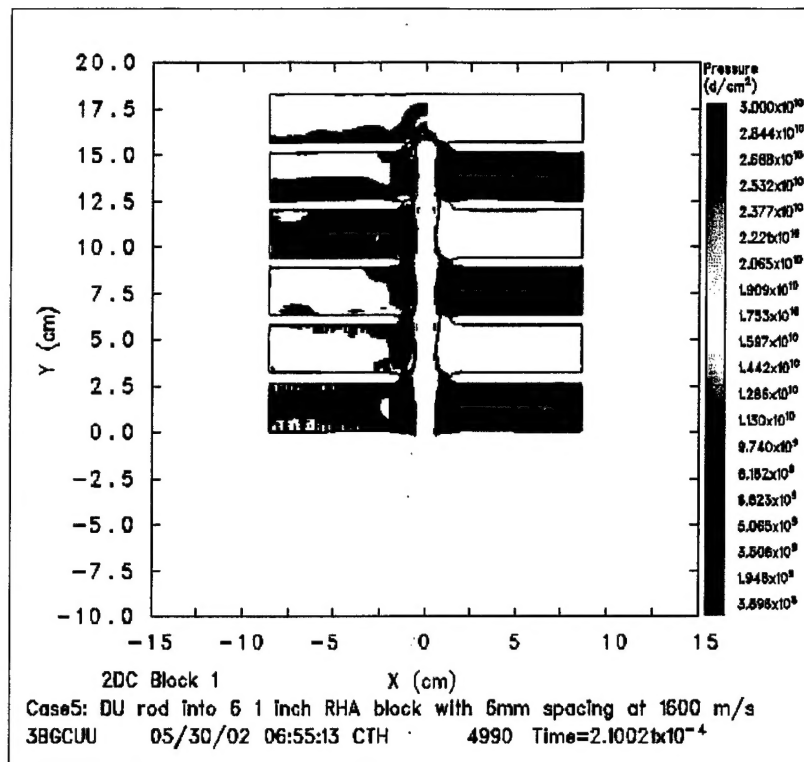
Figure 11. Computer simulation of penetration into stacked plates separated by 6-mm air gaps.

5. Conclusions

Our experiments reveal a clear trend in increased RHA penetration as we transit from the monolithic target through the progressively greater spaced targets. Additionally, the data highlight a difference in penetration even between the laminated targets without air gaps, and those that were laminated with a 3-mm built-in air gap. With a P/L difference of ~0.03 (3%) between those two target types, the influence on penetrator performance could be significant. While the predicted values from our computer simulations are comparatively lower than our empirical data, those predictions also indicate a similar trend of increased penetration from the monolithic through the spaced targets. The difference in P/L values between the monolithic target and spaced targets is 0.1 or 10%, for both the experimental data and our computer predictions. The potential significance of spacing effects on KE penetrator evaluation could be very significant. A 10% difference in penetration capability is a highly significant value when evaluating the performance of KE penetrators. Further experiments with full-scale long rod penetrators against targets with various spacing configurations should be conducted for further corroboration.

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14. ABSTRACT
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